Ecological Indicators 104 (2019) 107–115

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Original Articles

# Resilience of benthic macroinvertebrates to extreme floods in a Catskill Mountain river, New York, USA: Implications for water quality monitoring and assessment

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ARTICLE INFO

*Keywords:*
Bioassessment
Climate change
Macroinvertebrates
Streams
Hydrology

ABSTRACT

Changes in the timing, magnitude, frequency, and duration of extreme hydrologic events are becoming apparent and could disrupt species assemblages and stream ecosystems across the Northeastern United States. Between August 28 and 29 of 2011, an average of 31 cm of rain from Tropical Storm Irene fell across Eastern New York State in less than 24 h and caused historic flooding in numerous streams of the Catskill Mountain Region. Peak discharges exceeded the 0.01 annual exceedance probability (> 100 year flood) in many Catskill Mountain streams. Approximately one week later, the remnants of Tropical Storm Lee deposited another 19 cm of rain onto saturated soils and caused additional flooding. Data from annual benthic macroinvertebrate surveys completed at 5 sites in the Upper Esopus Creek, a premier trout stream in the region, during August 2009–2011 (before the floods) were compared to data collected from the same sites in September 2011, November 2011, March 2012 and August 2012 (after the floods). The impact, rate of recovery and the factors which might affect the resilience of benthic macroinvertebrate communities were evaluated. The results of biological water quality assessment metrics immediately after the floods resembled those of highly polluted waters, yet severe floods were the only disturbance. Prior to the floods, standard biological assessment metrics showed that communities were not impacted and water quality was pristine. A large decrease in macroinvertebrate density was evident in the September 2011 surveys following the floods and bioassessment metrics reflected highly degraded water quality conditions. Most community metrics rebounded in 3–7 months (November 2011 and March 2012), and full recovery was evident in 12 months (August 2012) which suggests that macroinvertebrate assemblages are relatively resilient to the effects of extreme floods in these low-order streams. Therefore, macroinvertebrate samples collected from a flood-impacted stream before full recovery occurs might reflect loss of diversity and abundance from the flood disturbance and incorrectly attribute the impact to impaired water quality. The strong short-term impacts and the relatively rapid recovery of macroinvertebrate communities following catastrophic floods have important ramifications for routine bioassessment programs considering changing hydrologic regimes in streams across the Northeast and elsewhere.

## 1. Introduction

When flooding occurs in lotic ecosystems, increased water velocity mobilizes substrate, scours microorganisms, and transports benthic macroinvertebrates and fish (Lamberti et al., 1991), acting as a significant influence on the structure of stream communities (Robertson et al., 2015). Large debris is often entrained in flood waters, further adding to scour and disturbing riparian corridors, removing canopy, and changing channel water temperatures and sediment composition (Danehy et al., 2012; Lamberti et al., 1991; Snyder and Johnson, 2006). Organisms are displaced from their natural habitat (Fingerut et al., 2015; Rempel et al., 1999), which decreases biodiversity and organism density (Bunn and Arthington, 2002; Scrimgeour and Winterbourn, 1989). Many benthic macroinvertebrate species have evolved adaptations in their behavior, life history, or reproductive abilities to resist typical floods or to recover quickly (Lamberti et al., 1991). Catastrophic flooding caused by tropical storms or hurricanes, however, can overwhelm the resilience of benthic macroinvertebrate communities in regions unaccustomed to such events (Snyder and Johnson, 2006; Turner and Dale, 1998).

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https://doi.org/10.1016/j.ecolind.2019.04.057
Received 10 August 2018; Received in revised form 15 April 2019; Accepted 16 April 2019
1470-160X/ Published by Elsevier Ltd.

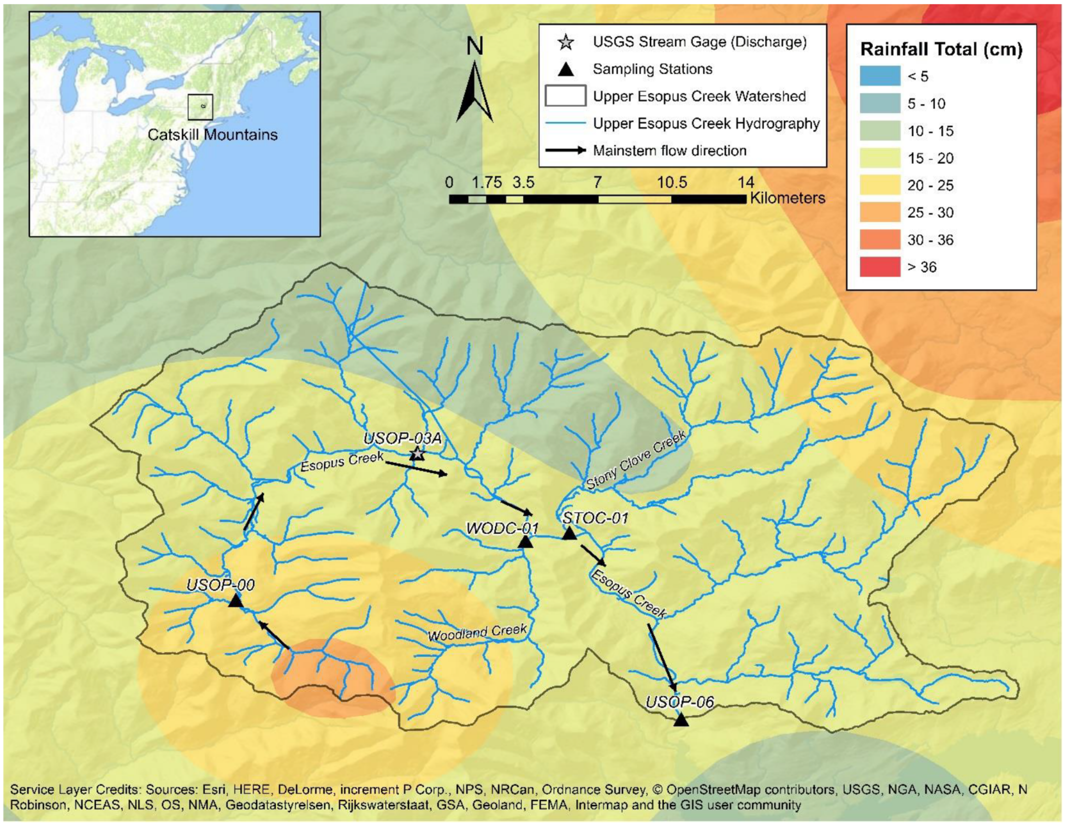


**Fig. 1.** Location of study sites in the Upper Esopus Creek watershed in New York and their relation to precipitation totals associated with Tropical Storm Irene during August 2011.

Climate-change impacts on ecosystem structure and function have been well documented (Grimm et al., 2013), causing substantial disturbance of aquatic species assemblages due to increased storm activity and flooding in many regions around the world. Increased sea-surface temperature is adding more water vapor to the atmosphere, leading to an increase in tropical storm frequency and intensity (Dale et al., 2001; Trenberth et al., 2018). The rise in sea-surface temperatures at higher latitudes is expected to cause more severe storm events in the Northeast United States (Dale et al., 2001; Trenberth, 2011). The Northeast has seen an increase in heavy precipitation, and will continue to do so into the future (Hayhoe et al., 2007; Planet and Wake, 2005; Rosenzweig et al., 2011). Increased precipitation is likely to increase the incidence of flooding, with urban areas and mountainous regions experiencing more frequent and larger flash floods (Rosenzweig et al., 2011). Unfortunately, even though many climate scenarios suggest increasing frequency and intensity of flood events, specifically in the Northeastern United States (Calderon et al., 2017), data to adequately capture natural system response is limited (Woodward et al., 2015).

The long term changes in precipitation and temperature associated with climate change may alter baseline surface water conditions which could affect biological water quality monitoring activities (Barbour et al., 2010). Due to the changes in the timing, magnitude, frequency, and duration of extreme flow events, benthic macroinvertebrate communities may more frequently be in a state of recovery from hydrologic disturbance. The rate of recovery following a hydrologic disturbance depends on the severity of the event, the physical attributes of the watershed, and the antecedent conditions (Danehy et al., 2012; Greenwood and Booker, 2015). In general, the recovery of lotic ecosystems is regulated by growth rates of resident species, reproduction/recruitment, immigration (from unaffected reaches), and recovery of useable habitat, with full recovery shown to take from several months to more than a year (Bae et al., 2014; Hoopes, 1974; Lamberti et al., 1991; Milner et al., 2018; Snyder and Johnson, 2006; Yount and Niemi, 1990) or longer (Woodward et al., 2015). In some instances, habitat may be permanently changed and the ecosystem may never recover to the same pre-event faunal composition (Hoopes, 1974; Milner et al., 2018).

Recent investigations suggest that an increase in the average stream temperature, associated with a warming climate, will also alter community composition (Hamilton et al., 2010; Lawrence et al., 2010; Scrine et al., 2017). Given that the current macroinvertebrate community bioassessment metrics are inherently incapable of discerning between thermal and hydrologic disturbance, these types of climate-related effects on macroinvertebrate communities may be inaccurately represented by bioassessment metrics, mistaken for more direct human/pollution disturbance. For example, finding aquatic communities of low abundance and low diversity suggests that some aspects of the aquatic environment, chemical composition and/or habitat quality, are not suitable for a full complement of biota. Storm events such as hurricanes and tropical storms, which can cause significant flooding and catastrophic drift of aquatic communities can result in low macroinvertebrate diversity and abundance. Therefore, macroinvertebrate samples collected from a storm-event-impacted stream before full recovery occurs might reflect loss of diversity and abundance from the disturbance and incorrectly attribute the low system quality to water pollution.

The main objective of the current study was to increase our understanding of the impacts and recovery from extreme flooding on communities of benthic macroinvertebrates. Using data from the Upper Esopus Creek in the Catskill Mountains of New York, USA we compare standard bioassessment metrics and community composition data from surveys conducted before flooding caused by the Tropical Storms Irene and Lee (August 2009, 2010, and 2011), to those completed one month post floods, three months post floods, seven months post floods, and

twelve months post floods to document community response (resistance to impact) and ascertain the timing of recovery (resilience). Such knowledge is vital for state agencies and others that evaluate water quality of streams and lakes using biological assessments. A better understanding of the effects of hydrologic disturbance and the recovery time for benthic macroinvertebrate communities, tied to better information on stream flows and temperature, will enable regulatory biomonitoring programs to separate climate-driven effects from water quality impairments. Based on the study results, we further provide relevant guidance for the adjustment of the current, and the development of new ecological indicators.

## 2. Methods

### 2.1. Study area

The Upper Esopus Creek is a premier trout stream located within the Catskill Mountain Region of New York State (NYS) (Fig. 1). Forested land comprises over 95% of the watershed that features glacial lacustrine clay deposits, which contribute substantial amounts of suspended sediment to the system. This study provided ideal pre-flood events datasets for comparison with data collected after flooding caused by Tropical Storms Irene and Lee. The response of fish communities to Tropical Storms Irene and Lee is described in George et al. (2015) while the response and recovery of benthic macroinvertebrate communities is discussed herein.

### 2.2. Tropical storms Irene and Lee

Record floods were observed on numerous occasions across New York in 2011 due to above average rainfall and heavy spring snow melt. Consequently, pre-existing saturated soils and elevated stream flows exacerbated flooding from Tropical Storm Irene when it moved through the Upper Esopus Creek watershed on August 28 and 29, 2011. Per Lumia et al. (2014) rainfall across the region averaged 31 cm in less than 24 h, causing some of the most severe floods ever recorded at many USGS stream gages in the region. Rainfall total from this event in the Upper Esopus Creek was the 5th highest of any watershed in the Northeast. A USGS stream gage located in the Upper Esopus Creek at Allaben, New York (Fig. 1) with a period of record beginning in 1964 recorded peak discharge for the event at 830 cubic meters/second ($m^3$/s) with an annual exceedance probability (AEP) between 0.01 and 0.005 (recurrence interval of 100-to-200 years). The peak discharge from this flood was 215 $m^3$/s greater than the next highest peak discharge for the site which occurred in 2005 (Lumia et al., 2014). Four other stream gages in the watershed recorded peak discharges with AEPs ranging from 0.143 to 0.012 (recurrence intervals of 7–80 years). Discharge had nearly receded to pre-flood levels at which point approximately 19 cm of rain related to Tropical Storm Lee fell between September 5–8th, again creating catastrophic flooding in the watershed (Lumia et al., 2014). The AEPs for peak flows during this flood varied between > 0.500 and 0.333 (recurrence intervals of > 2–3 years) at the five stream gages.

### 2.3. Collection of benthic macroinvertebrates

The NYS Department of Environmental Conservation (NYSDEC) and the U.S. Geological Survey (USGS) sampled benthic macroinvertebrates, periphyton, fish, stream discharge, and water chemistry in the Upper Esopus Creek and tributaries from 2009 to 2011 (Smith, 2013) as part of a collaborative project investigating the effects of supplemental flows and turbidity on water quality and stream ecosystems across the watershed (Baldigo et al., 2015; George and Baldigo, 2015; George et al., 2016; McHale and Siemion, 2014). Benthic macroinvertebrate communities were sampled after the floods in September and November 2011, and March and August 2012, at 5 main-stem and tributary sites previously sampled in 2009, 2010, and 2011 (Fig. 1). The last sampling prior to Tropical Storm Irene occurred on August 25, 2011, three days before the floods. Collection of benthic macroinvertebrates followed standard NYSDEC methods (NYSDEC, 2012). Benthic macroinvertebrates were dislodged by kicking stream substrates, while moving downstream along a 5 m diagonal transect through a riffle for a period of 5 min. At each of the five sites, four replicate samples were collected in different areas of the same riffle, staying within the main channel flow. All organisms were collected using a standard 22.9 cm by 45.7 cm kick net with 0.8 mm by 0.9 mm mesh. Replicate samples were preserved separately by sieving material with a U.S. no. 30 sieve, transferring to a plastic quart jar, and adding 95% ethyl alcohol (NYSDEC, 2012), before shipping to a contract laboratory (Watershed Assessment Associates, LLC, Schenectady, NY 12303) for processing. Macroinvertebrates larger than 1.5 mm were removed from the debris of each of four, separate replicate samples, until a 100-organism subsample of organisms larger than 1.5 mm was obtained from each of the four replicates. Chironomidae and Oligochaeta were cleared and slide-mounted and all organisms were identified to lowest possible taxonomic resolution (usually genus or species) and enumerated.

### 2.4. Bioassessment metrics and the biological assessment profile score

To assess impacts to aquatic life in surface waters of NYS, the NYSDEC summarizes benthic macroinvertebrate community data using a multimetric index of biological integrity. This multimetric, known as the Biological Assessment Profile (BAP) score, is used statewide to assess water quality condition. The BAP consists of four component metrics including species richness (Spp), Ephemeroptera–Plecoptera–Trichoptera richness (EPT) (Lenat, 1988), Hilsenhoff's biotic index (HBI) (Hilsenhoff, 1987), and percent model affinity (PMA) (Novak and Bode, 1992). The result of each metric is placed on a common 10 scale and the mean of these adjusted values is calculated. The resulting BAP score is a single value for which a four-tiered scale of water quality impact (non, slight, moderate, or severe) has been established (NYSDEC, 2012). Sampling results that fall within the moderate or severely impacted categories represent significant impacts to aquatic life and result in listing on the NYS 303(d) list of impaired waterbodies. We also analyzed changes in the relative density of benthic macroinvertebrates using the percent of sample sorted to reach the target subsample of 100 organisms. Although not a component metric of the BAP, the percent of sample sorted is a useful surrogate measure of macroinvertebrate density indicating the amount of effort (percent of sample) required to reach the fixed-count subsample size. Samples with low organism density generally require a greater percentage of the sample to be processed, whereas samples with high density usually require a low percentage of the sample to be processed to reach the same 100 count subsample.

### 2.5. Statistical analyses

Two analyses were used to characterize the overall effects of the floods on local macroinvertebrate communities, how specific taxonomic groups were impacted, and the rate at which various metrics and the composition of communities recovered after the floods. First, Friedman Repeated Measures Analysis of Variance on Ranks (RM-ANOVA) and pairwise multiple comparison procedures (Tukey Test) were used to determine if the BAP scores, component metrics, and density differed significantly ($\alpha = 0.05$) among the seven sampling periods. These tests, therefore, determined if the impacts were significant and how quickly each metric recovered to pre-flood condition. The impacts of seasonality on these metrics was investigated through comparison of BAP scores with those of seasonally different replicated samples from three other rivers in NYS including the Cohocton, Hoosic, and West Branch Delaware Rivers. We performed the same RM-ANOVA on BAP scores between seasonally replicated samples from each of these streams to

determine if significant differences exist in BAP scores between seasons in other systems.

Second, temporal changes in community composition were evaluated using multivariate techniques with PRIMER-E version 6 software. Macroinvertebrate taxa counts were square-root transformed and community similarity between samples was analyzed using Bray Curtis distances (Primer-E Ltd, Lutton UK). A one-way Analysis of Similarities (ANOSIM) test was used to test the null hypothesis that communities did not differ between survey periods (Clarke and Gorely, 2006). Differences in community composition among survey periods were assessed based on the permutation distribution of the ANOSIM test statistic "R" (Clarke and Gorely, 2006). Values closer to 0 ($R < 0.25$) represent no difference in community composition while those closer to 1 ($R > 0.75$) represent a significant difference (Clarke and Gorely, 2006; Ramette, 2007). Additionally, the similarity of macroinvertebrate communities between all survey periods was displayed using a non-metric multidimensional scaling ordination (nMDS), representing information from the Bray-Curtis distance matrix. This ordination was used to evaluate taxonomic composition at all sites before and after the floods. By observing the distance and location of samples in species ordination space relative to the floods, we made inferences regarding the resistance, resilience, and recovery of the benthic macroinvertebrate communities. Similarity Percentages (SIMPER) analysis was used to identify taxa that contributed most strongly to sample dissimilarity between groups observed in the nMDS (Clarke and Gorely, 2006). SIMPER produces pairwise comparisons of all samples and from these comparisons it can be determined which taxa cause the greatest dissimilarity between each pair of surveys or groups of surveys (Clarke and Gorely, 2006). Using the groups of surveys that showed the largest differences in community composition, we classified sites into four flood-effect categories. These categories were defined as *pre-flood* (August 2009, 2010, 2011), *response* or impact (September 2011), partial *recovery* (November 2011, March 2012), and full *post-flood* recovery (August 2012). SIMPER was used to compute the average dissimilarities among the four categories based on the occurrence of individual taxa.

## 3. Results

The four metrics included in the BAP index suggested that the floods from storms Irene and Lee had adverse impacts on water quality across the Upper Esopus Creek watershed. The average BAP scores of the five sites showed water quality was non-impacted during all three surveys (2009–11) prior to the floods (Fig. 2). Immediately following the floods, BAP scores from the September survey indicated water quality was slightly to moderately impacted. The mean BAP scores rebounded partially in November and March, and reached non-impacted levels by August 2012 (Fig. 2). For all metrics except HBI, results of the RM-ANOVA and Tukey's multiple comparison test found the communities present in September 2011 were significantly different ($P \leq 0.05$) from all other surveys, except March 2012. The metrics (Spp, PMA, and EPT) declined significantly in September immediately after the floods. The BAP and most component metrics recovered partly by the November 2011 and March 2012 surveys, but remained significantly different from their August 2009, 2010, and 2011 norms (Figs. 2, 3a, b, and d). Unlike the response of other metrics, the small decline in mean HBI during September continued through November and March 2012. By August 2012, however, none of the component metrics differed significantly from their August 2009–11 levels (Figs. 2, 3a–d). Results of the RM-ANOVA on seasonally collected samples from the Cohocton, Hoosic, and West Branch Delaware Rivers suggest no statistically significant difference in BAP scores between seasons from non-flood impacted streams. These watersheds are valuable for comparison with results from the Upper Esopus Creek because, while larger in drainage area, their watershed characteristics are very similar. For example, like the Upper Esopus Creek, these watersheds are dominated by forest, have very small amounts of development and impervious surface, and

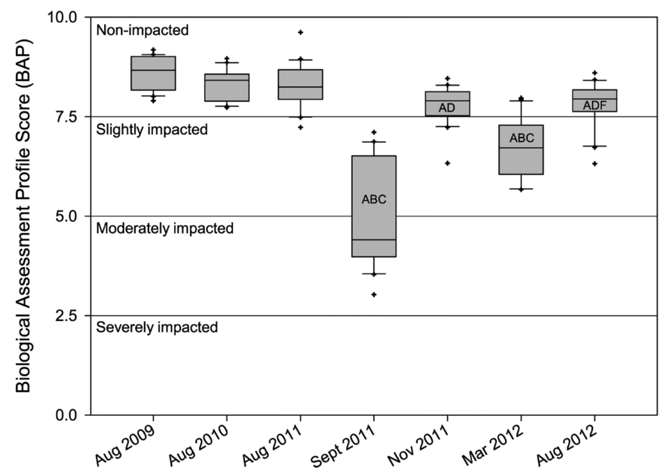


**Fig. 2.** Boxplots depicting the median, 25th and 75th percentiles (shaded boxes), the 10th and 90th percentile values (whiskers), and outliers for the bioassessment profile (BAP) scores in all macroinvertebrate samples collected at five sites grouped by survey month and year. Boxes with the same letter differ significantly using Tukey's test. Box letters are A, B, C, D, E, F, G from left to right.

have greater than 50% of their area at or above 1200ft elevation (Table 1). These results support the conclusion that differences observed in the Upper Esopus Creek are the result of impacts from the flood events and not seasonality.

An analysis of the percent of sample sorted to obtain 100 organisms indicated that the density of macroinvertebrates at all sites was relatively consistent before the floods, declined sharply following the floods, and recovered rapidly (Fig. 4). Like the BAP, Spp., EPT, and PMA, Tukey's multiple comparison test indicated that the percent of sample sorted did not differ significantly among the three surveys before the floods. Macroinvertebrate densities were so depleted immediately after the floods (September 2011) that the target 100-organism subsample could not be obtained in any kick sample, even after 100% of the debris was sorted. The mean percentage of sample sorted to obtain the target 100-organism subsample before the floods ranged from 32 to 50% and was significantly less than that in September after the floods (set at 100%). The percent of sample sorted decreased substantially (densities increased) during each subsequent survey after September, and by August 2012, the percentage of sample sorted at the sampling locations was significantly greater than pre-flood condition with an average of less than 10% of sample material sorted to reach the target count (Fig. 4).

Results from the nMDS suggest that the composition of macroinvertebrate communities at all sites was most similar between the three pre-flood (August 2009–11) surveys and the 1-year post floods (August 2012) survey (Fig. 5). This indicates that macroinvertebrate communities were, for condition assessment purposes, completely recovered one year following the floods. Some of the largest (and most variable) divergence from clusters of similar sites occurred in the September survey one month after the floods (Fig. 5). The ordination also suggests that community composition at most sites in November 2011 and March 2012 was quite dissimilar to the communities sampled at the same sites during most other surveys. Results from the ANOSIM test, which evaluates differences in community composition between surveys, confirmed the observations from the nMDS (Fig. 5) and the responses of bioassessment metrics. The ANOSIM indicated that community composition differed significantly ($R = 0.708$, $P \leq 0.001$) between surveys. Thus, $H_o$ was rejected in favor of $H_a$ which states that differences in community composition exist between surveys.

The pairwise comparisons of community composition between each survey period are shown in Table 2. The results indicate that communities were most dissimilar between the surveys conducted (a)

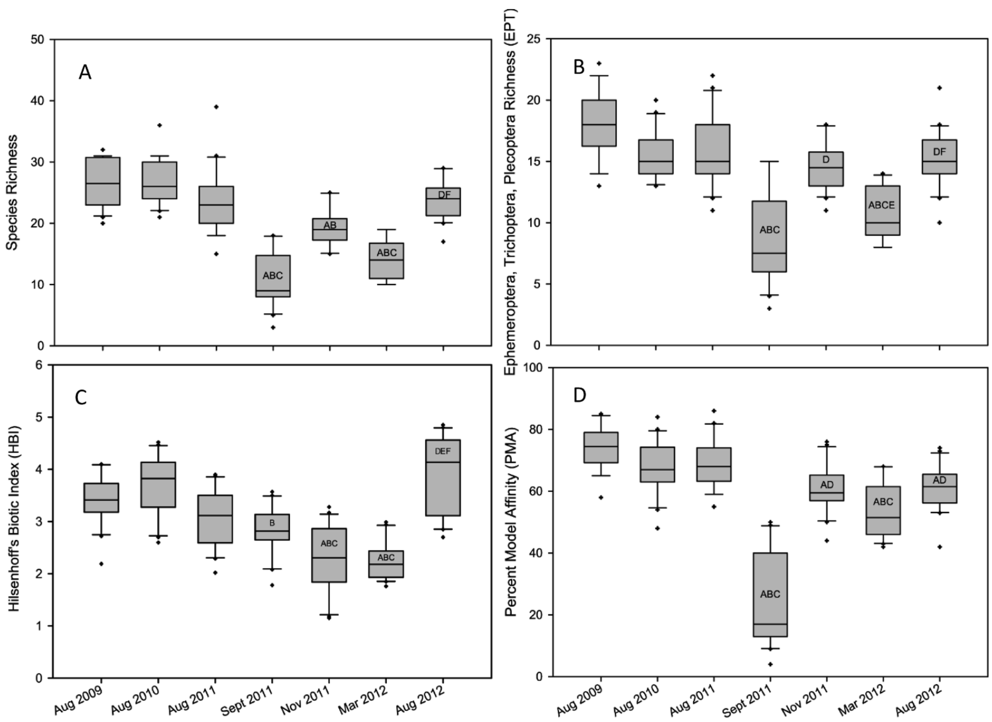


**Fig. 3.** Boxplots depicting the median, 25th and 75th percentiles (shaded boxes), the 10th and 90th percentile values (whiskers), and outliers for (A) species richness, (B) Ephemeroptera, Plecoptera, Trichoptera richness (EPT) richness, (C) Hilsenhoff's Biotic Index (HBI), and (D) Percent Model Affinity (PMA) in all macroinvertebrate samples collected at five sites grouped by survey month and year. Boxes with the same letter differ significantly using Tukey's test. Box letters are A, B, C, D, E, F, G from left to right.

**Table 1**
Watershed characteristics for comparison with the Upper Esopus Creek. These watersheds and their seasonal monitoring data were used to suggest the differences observed in Esopus Creek samples were not related to seasonality.

| River | Drainage Area (sq. miles) | % 1200ft | % Forest | % Developed | % Impervious |
|---|---|---|---|---|---|
| Upper Esopus Creek | 191 | 85 | 97 | 2 | 0.2 |
| W. Br. Delaware River | 353 | 99 | 76 | 4 | 0.4 |
| Hoosic River | 573 | 51 | 75 | 7 | 2.0 |
| Cohocton River | 597 | 90 | 66 | 5 | 0.7 |

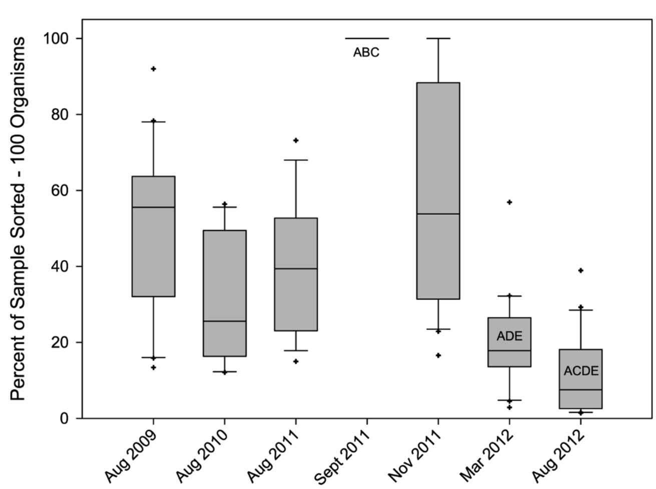


**Fig. 4.** Boxplots depicting the median, 25th and 75th percentiles (shaded boxes), the 10th and 90th percentile values (whiskers), and outliers for the percent of sample sorted to reach the target 100-organism subsample in all macroinvertebrate samples collected at five sites grouped by survey month and year. Boxes with the same letter differ significantly using Tukey's test. Box letters are A, B, C, D, E, F, G from left to right.

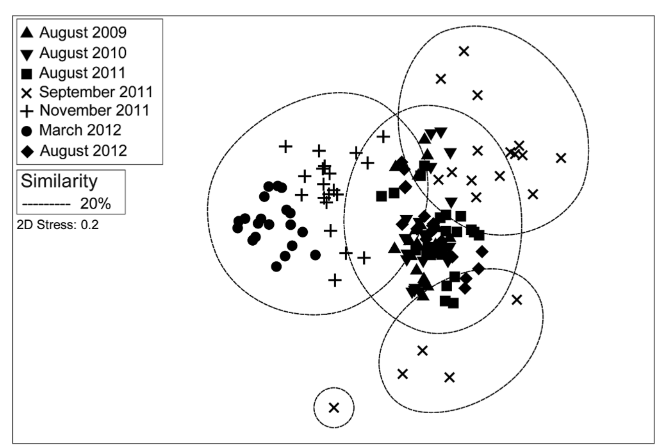


**Fig. 5.** Non-metric multidimensional scaling ordination (nMDS) displaying sample similarity based on Bray-Curtis distances. Samples showing ≥ 20% similarity between sample species composition are circled.

immediately following the flood events (September 2011), (b) during recovery (November 2011 and March 2012), and (c) during summer base flow periods (August 2009, 2010, 2011, and 2012) (Table 2).

The SIMPER analysis identified various macroinvertebrate taxa most responsible for the differences between surveys observed in ANOSIM and the nMDS ordination. Using the information from the results of the SIMPER analysis showing the largest differences in community composition, four distinct flood-effect categories were identified. These include *Pre-flood* (August 2009, 2010, 2011), *Response* or impact (September 2011), partial *Recovery* (November 2011, March 2012), and full *Post-flood* recovery (August 2012). Using SIMPER we computed average dissimilarities among the four categories based on

**Table 2**
Pairwise comparisons of the ANOSIM test with 999 permutations showing macroinvertebrate community, rank dissimilarity between surveys. Values closer to 0 represent little or no differences in macroinvertebrate community composition and those close to 1 represent large differences.

| Aug 2009 | Aug 2009 | Aug 2010 | Aug 2011 | Sep 2011 | Nov 2011 | Mar 2012 |
|---|---|---|---|---|---|---|
| Aug 2010 | 0.281 | | | | | |
| Aug 2011 | 0.091 | 0.323 | | | | |
| Sep 2011 | 0.673 | 0.652 | 0.528 | | | |
| Nov 2011 | 0.943 | 0.884 | 0.932 | 0.779 | | |
| Mar 2012 | 0.986 | 0.990 | 0.990 | 0.873 | 0.907 | |
| Aug 2012 | 0.510 | 0.303 | 0.341 | 0.653 | 0.922 | 0.999 |

**Table 3**
List of specific taxa which cumulatively account for 50% of the dissimilarity between sample event groups. Values represent their percent contribution to the dissimilarity between sample groups. Sample groups are classified as Pre-flood (Pre.), Response (Res.), Recovery (Rec.), and Post-flood (Post.).

| Taxon | Percent Dissimilarity Between Sample Groups | | | | | |
|---|---|---|---|---|---|---|
| | Pre. vs. Post. | Pre. vs. Rec. | Pre. vs. Res. | Rec. vs. Post. | Res. vs. Post. | Res. vs. Rec. |
| *Acentrella turbida* | 2.47 | 2.85 | 4.25 | 1.97 | 2.65 | |
| *Allocapnia* sp. | | 1.56 | | | | 2.40 |
| *Baetis flavistriga* | 2.29 | 1.92 | 2.56 | 2.67 | 3.62 | |
| *Baetis tricaudatus* | 2.58 | 3.09 | 3.04 | 3.54 | | 5.73 |
| *Cheumatopsyche* sp. | 2.07 | 1.73 | 2.05 | 2.55 | 2.97 | |
| *Cinygmula* sp. | | 2.95 | | 3.17 | | 4.80 |
| *Cricotopus bicinctus* | 2.84 | | | 2.51 | 3.39 | |
| *Cricotopus trifascia* gr. | 1.69 | | | | | |
| *Diamesa* sp. | | 2.49 | | 2.68 | | 3.93 |
| *Dolophilodes* sp. | 1.99 | 1.88 | 2.48 | | | |
| *Epeorus* sp. | | 5.93 | | 7.13 | | 11.06 |
| *Epeorus vitreus* | 2.06 | | 1.99 | | | |
| *Ephemerella dorothea* | | | | | | 2.47 |
| *Ephemerella* sp. | 1.79 | 2.42 | 1.97 | 2.48 | 2.28 | 4.02 |
| *Hydropsyche morosa* | 2.98 | 2.23 | 2.83 | 2.97 | 3.85 | |
| *Hydropsyche slossonae* | 2.78 | 2.18 | 2.95 | 3.68 | 4.35 | 2.93 |
| *Hydropsyche sparna* | 2.49 | 1.68 | 2.00 | 2.97 | 3.86 | |
| *Isogenoides* sp. | | | 1.87 | | | |
| *Isonychia* sp. | 2.74 | 3.45 | 4.11 | 3.30 | 3.62 | |
| *Lepidostoma* sp. | 1.69 | | | | | |
| *Micropsectra dives* gr. | 3.22 | 2.74 | 3.69 | | | |
| *Orthocladius* sp. | 1.81 | | | | 2.30 | |
| *Paragnetina immarginata* | 1.96 | 1.76 | 2.23 | | | |
| *Paraleptophlebia* sp. | | 1.60 | | | | 2.65 |
| *Polypedilum aviceps* | | | | | 2.09 | |
| *Polypedilum flavum* | 3.32 | 2.91 | 3.88 | | | |
| *Maccaffertium* sp. | 1.69 | | 4.16 | | 4.55 | 5.07 |
| *Maccaffertium vicarium* | 4.31 | 2.86 | 4.19 | 4.80 | 7.22 | 2.47 |
| *Strophopteryx* sp. | | 2.78 | | 2.98 | | 4.32 |
| *Thienemannimyia* gr. | 2.29 | | | 2.35 | 3.25 | |

the occurrence of individual taxa. The results of this analysis were comparable to that of ANOSIM in that communities were found to differ most immediately after the floods, less so during the recovery period, and least during the pre-flood and post-flood surveys. Of particular interest, the following taxa accounted for substantial dissimilarity between groups (Table 3); *Polypedilum flavum* (Diptera: Chironomidae) and *Acentrella turbida* (Ephemeroptera: Baetidae) were partly responsible for the dissimilarity between Pre-flood and Response conditions while *Isonychia* spp. (Ephemeroptera: Isonychiidae) and *Hydropsyche slossonae* (Trichoptera: Hydropsychidae) were partly responsible for dissimilarity between Recovery and Post-flood conditions. Comparing differences in the density of these taxa across the four categories (Fig. 6) indicated that taxa with high abundance prior to the flood events such as *Hydropsyche slossonae* and *Isonychia* spp. persisted even during the Response phase. In contrast, taxa in lower abundance prior to the event such as *Acentrella turbida* and *Polypedilum flavum* were absent from most samples immediately following the floods.

## 4. Discussion

As a result of the work described here in the Upper Esopus Creek it is clear that biological monitoring programs working in hydrologically altered river reaches (due to floods and possibly droughts), using current indicators, bear a high risk of producing misleading results. These indicators may therefore suggest pollution as the primary disturbance, while the only disturbance may be natural and hydrologic in nature. Therefore, significant changes in macroinvertebrate communities in the Upper Esopus Creek after severe floods demonstrate that some period of recovery is necessary before standardized bioassessment metrics, used in a regulatory setting, are again indicative of actual water quality conditions.

One of the most striking findings of this investigation is the disparity between average BAP scores from immediately before and after the floods in the Upper Esopus Creek. The average BAP scores during the three pre-flood surveys were > 8.0 which would rate water quality as non-impacted. In September 2011, approximately two weeks after the floods, the average BAP score was only 4.9, which suggested moderately impacted water quality. This is a substantial decline considering the 2011 pre-flood samples and the September 2011 post-flood samples were collected less than three weeks apart. The significant reduction in BAP scores post flooding suggests some species were temporarily eliminated from the system, drastically restructuring benthic communities. The recent work of others suggests similar results, where some species declined and returned to pre-flood levels quickly while others were lost completely (Milner et al., 2018; Woodward et al., 2015). These community shifts are visible among common measures of richness and diversity along with functional group metrics (Calderon et al., 2017; Greenwood and Booker, 2015; Woodward et al., 2015). Our findings, in the context of others, suggest hydrologic disturbances have the potential to confound biological assessments of water quality. We suggest then, that it would be reasonable to conduct future research focused on identifying the flood-tolerant, but pollution-sensitive taxa, to develop more pollution-focused ecological quality indicators.

The differences observed in assessment metrics were not related to natural, seasonal variation in macroinvertebrate community composition. Most long-term studies of macroinvertebrate communities collect samples during similar month(s) year-to-year to rule out expected seasonal variations in community composition resulting from natural growth and emergence patterns. Similarly, this approach was conducted here, with the recurring, consistent, collection taking place during the month of August (2009, 2010, 2011, and 2012). However, to capture the immediate response to the flood events, and understand how quickly communities recovered, additional sampling was conducted during September 2011, November 2011, and March 2012. It cannot be ignored then that this difference in sampling period draws into question the differences in community assessment metrics observed, such as the BAP, and whether they result from nothing more than seasonal differences in community composition (i.e. the natural differences expected under non-flood, year-round conditions). For that reason, additional information on seasonal variability in macroinvertebrate community metrics during non-flood years from other rivers in New York was used in comparison against this study. The RM-

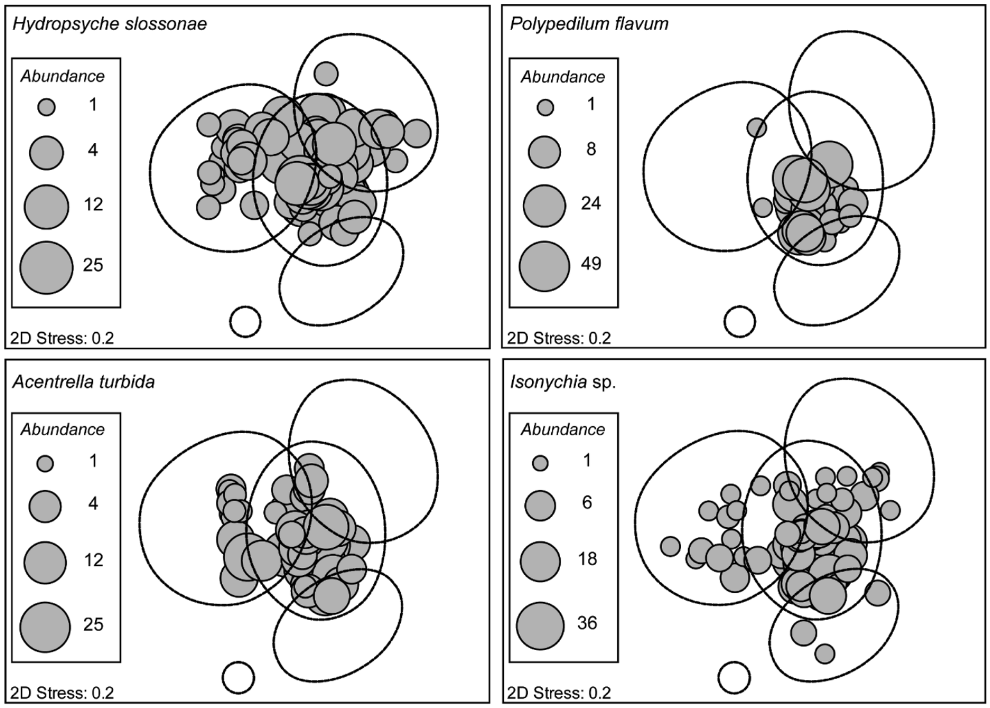


**Fig. 6.** Bubble plots showing abundance of four taxa imposed on the non-metric multidimensional scaling ordination (nMDS). Circles represent ≥ 20% similarity between samples.

ANOVA and summary statistics on variability in BAP scores suggest no statistical differences between seasons in three additional rivers investigated (Cohochton, Hoosic, and West Branch Delaware). If natural seasonal variability were a cause for the dramatic differences observed in BAP and other metrics in the Upper Esopus Creek then we should equally expect similar differences between seasons in these rivers. The lack of difference supports the conclusion here that post-flood samples reflect macroinvertebrate communities in recovery from severe habitat alterations and only minimal influence from seasonality.

Though not a component of the NYS BAP, the density metric provided useful information for assessing the impact and rate of recovery of benthic macroinvertebrate communities following the floods in the Upper Esopus Creek. This finding was not surprising because density is frequently used to characterize the response of benthic communities to flooding (Angradi, 1997; Bae and Park, 2016; Fingerut et al., 2015; Fisher et al., 1982; Greenwood and Booker, 2015; Hendricks et al., 1995; Hoopes, 1974; Robinson et al., 2004; Scrimgeour and Winterbourn, 1989; Siegfried and Knight, 1977; Sueyoshi et al., 2017; Woodward et al., 2015). The routine sampling method (traveling kick) and metrics used in NYS do not include a direct measure of density. However, a surrogate measure of density (percent of sample sorted to reach the target count of 100 specimens) showed that > 60% more effort had to be expended to even approach the target count following the floods (Fig. 4). This significant reduction in the densities of invertebrates is likely a contributing factor for the poor outcome of water quality metrics. There is likely a threshold at which a critical number of organisms should be present in order to calculate macroinvertebrate bioassessment metrics and have them be an accurate representation of water quality. Below this threshold we might expect assessments to reflect poor water quality regardless of stressor, natural or manmade disturbance. Unfortunately, we have never evaluated assessment metrics in this way, but it is worth considering when conducting these types of assessments post disturbance. It is likely something that should be evaluated further, in the future. Nevertheless, the significant change in macroinvertebrate densities suggests that density may be a useful tool in characterizing both flood disturbance and progression of recovery. We suggest this because, in most cases, overall macroinvertebrate community density does not decline significantly with water pollution (Stone et al., 2005; Xu et al., 2014). Therefore, it would be reasonable to consider a threshold of density to include in multi-metric indices, below which might be indicative of hydrologic disturbance. Monitoring programs not currently measuring densities in some manner might, therefore, consider adding this metric to their routine assessments. In this way, we suggest that density was a very good indicator of hydrologic disturbance, one that is not normally connected to increased water pollution (Stone et al., 2005; Xu et al., 2014). Therefore, declining densities in otherwise healthy aquatic systems might prove to be effective early indicators of shifts in flow regimes related to changing climatic conditions.

The diverse assemblage of species that comprise macroinvertebrate communities in the Upper Esopus Creek exhibit a wide array of life histories and adaptations, such as voltinism, swimming and feeding habits, and attachments to substrates, which increase resistance and/or resilience to flood disturbance. Although most species were severely depleted by the floods, a select few accounted for the initial rapid recovery of local communities after the floods. Several abundant taxa were clearly impacted by the floods as they were completely absent from samples during the Response and some of the Recovery phases. For example, *Polypedilum flavum* (Diptera: Chironomidae) and *Acentrella turbida* (Ephemeroptera: Baetidae) were partly responsible for the dissimilarity between Pre-flood and Response conditions while *Isonychia* spp. (Ephemeroptera: Isonychiidae) and *Hydropsyche slossonae* (Trichoptera: Hydropsychidae) were partly responsible for dissimilarity between Recovery and Post-flood conditions. The ordinations associated with these taxa (Fig. 6) illustrate the differing responses of macroinvertebrate taxa in the Upper Esopus Creek watershed.

The characteristics of the macroinvertebrate communities likely played a significant role in how quickly the community composition reflected pre-flood assemblages. Focusing on the aforementioned taxa, we can identify distinct life history traits or habits that influence the degree of impact they felt from the flood event. For example, these taxa are known to prefer shallow, swiftly flowing, riverine environments, the dominant habitat of the Upper Esopus Creek watershed. However, *A. turbida* and *P. flavum,* which were abundant *pre-flood*, absent during

*response* and *recovery* periods, and abundant again *post-flood*, are highly susceptible to scouring events because they tend to live fully exposed to currents on rock surfaces (Burian and Gibbs, 1991; Edmunds et al., 1976; Maschwitz and Cook, 2000). This, in contrast to *Isonychia spp*. and *H. slossonae*, which exist protected from currents in debris piles or attached netting/enclosures respectively (Burian and Gibbs, 1991; Edmunds et al., 1976; Schmude and Hilsenhoff, 1986) is likely why these two taxa maintained more consistent abundance during *response*, *recovery*, and *post-flood* periods compared with *A. turbida* and *P. flavum.* Furthermore, although these taxa are univoltine, some may have multiple cohorts giving them an advantage in recovery from disturbance due to variable life stages present at the same time, each of which may have varying degree of susceptibility to scour. For example, *A. turbida* and *Isonychia* spp. are both univoltine but *Isonychia spp*. typically has multiple cohorts whereas *A. turbida* has one (Burian and Gibbs, 1991). These types of differences in life history will impact the community composition present in the system for recolonization *post-flood*.

Abundance prior to the floods may be extremely important in dictating which taxa recover fastest to pre-flood status. Most of the taxa present in November 2011, three months after the initial impact of the floods, were among the most abundant taxa collected in samples prior to the floods. These taxa included *Epeorus* spp. (Ephemeroptera: Heptageniidae), *Maccaffertium vicarium* (Ephemeroptera: Heptageniidae), *Isonychia* spp., *Baetis tricaudatus* (Ephemeroptera: Baetidae), and *Hydropsyche slossonae*, and together composed abundance of 20–40 individuals per 100 organism subsample. Therefore, it appears abundance in the ecosystem pre-flood may be a strong indicator of a species with high potential for recolonization following a catastrophic flood. Since the results of this study suggest some taxa recovered quickly after the floods, in comparison to others, biological assessment metrics would benefit from capitalizing on these responses to develop hydrologic disturbance sensitive metrics. Therefore, future research should focus on finding taxa which are minimally affected by hydrological disturbance and simultaneously sensitive to pollution. These taxa could then be used in the development of new, hydrologically insensitive indices.

Investigating the impact and recovery of benthic macroinvertebrate communities in the Upper Esopus Creek following the 2011 floods provided useful information regarding the effects of flood disturbance on biological assessment methods. The results of biological water quality assessment metrics resembled those of highly polluted waters, yet severe floods were the only disturbance. Recovery of local communities was relatively rapid, and complete by the following year in August of 2012. Similarly, macroinvertebrate densities were substantially reduced but also recovered by the following year. Therefore, we caution the analysis of biological monitoring data within the 12 months following a flood event. Recovery time from floods could be longer in watersheds with preexisting pollutant problems and in watersheds where several floods have occurred in the same year. Such recommendations should be fully considered in regulatory water-quality monitoring programs to ensure that water-quality issues are not confused with climate induced impacts.

## Acknowledgements

The authors thank the State of New York's New York City Safe Drinking Water Act for funding, New York State Department of Environmental Conservation's Stream Biomonitoring Unit for their assistance in sample collection and processing, and the U.S. Geological Survey for their long-term program support. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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